A METHOD FOR CALIBRATION OF A METROLOGY STAGE

Technical field

The present invention relates to a method for calibration of a metrology stage in a measuring apparatus, preferably a pattern generating apparatus, as defined in claim 1 and claim 5.

Background to the invention

Two-dimensional (2D) coordinate stages are used in many stages of very-large-scale-integrated (VLSI) circuit fabrication, to position lithography masks and move wafers to predetermined positions with high degree of reproducibility and accuracy. Typical tools which incorporate 2D-coordinate stages include electron and laser beam pattern generators in mask making, optical steppers in wafer printing and placement inspection tools in mask metrology.

In conventional photolithographic processing of semiconductor wafers, a plurality of masks is used in sequence to define microelectronic structures and features therein. Of course, in order to ensure that the features produced with a first mask are properly aligned to features produced with a second mask during a subsequent process step, it is typically necessary that the two masks be properly aligned relative to each other and that the mask patterns used to define the features be accurately located on each mask. In the past, the mask making industry faced little technical challenge in meeting the alignment and accuracy challenges posed by semiconductor process designers, even as critical photolithographic linewidths decreased by a factor of ten (10). The ability to meet these early challenges was due, at least in part, to high resolution and placement accuracy provided by mask pattern generators and the transition in wafer exposure tools from

predominantly 1 x optical lithography to 5 x reduction optical lithography. However, as critical photolithographic linewidth feature sizes continue to shrink, improved techniques and equipment for meeting more precise alignment and accuracy challenges are required.

During fabrication of integrated circuits, a semiconductor wafer is typically mounted on a 2D-coordinate stage. Typically, the (u,v) position and movement of the stage is monitored by a laser-interferometer. As will be understood by those skilled in the art, the measured (u,v) position of the stage will most often contain a deviation from the actual position of the stage in Cartesian coordinates. This deviation is typically referred to as the stage position measurement error. The Cartesian coordinate system has straight and uniform (x,y) grid lines which are orthogonal and have the same scale. As will be understood by those skilled in the art, the stage position measurement error is the sum of (i) random measurement noise (which can be caused by noise in circuitry, mechanical vibration, and air movement, etc.) and (ii) systematic measurement error (which is a function of the stage position, and can arise from, for example, the non-orthogonality between the x-y mirrors, curvature of the mirrors, etc.). The systematic measurement error is also called stage distortion. Accordingly, a proper calibration of 2D-coordinate stages generally requires the determination of the stage distortion by mapping the measured stage position to its respective position in the Cartesian coordinate grid.

Most stand-alone apparatus that have 2D-coordinate stages for VLSI processing and testing constitute a 2D-coordinate metrology system (e.g. mask placement inspection tools) or have 2D-metrology capability (e.g. electron-beam pattern generators and optical steppers). When using these apparatus,

stage distortion typically manifests itself as a coordinate measurement error when measuring marks having known positions on a rigid artefact plate ("standard plate").

The measurement of marks on a standard plate is a form of conventional calibration typically requiring two steps. The first step measures a standard plate having mark positions that are known to a higher degree of precision than the stage grid. The second step determines a mapping function (stage calibration function) between the measured coordinates and the actual coordinates, using a piece-wise linear function or polynomial fitting, as an approximation to the actual stage distortion.

Unfortunately, the use of standard plates to calibrate 2D metrology stages is no longer generally feasible because it is difficult to fabricate plates with mark positions at locations known with higher levels of accuracy than the levels obtainable with state-of-the-art metrology tools. To address this fundamental problem, self-calibration techniques have been developed to calibrate metrology stages using artefact plates with an array of mark positions having locations that are not precisely known. The only requirement is that the artefact plate is "rigid" so that the relative positions of the marks on the plate do not change when the plate is rotated or translated on the stage.

In US 4,583,298 to Raugh, conventional self-calibration techniques are disclosed. Some conditions for achieving complete self-calibration were pointed out:

1) There must be at least three different measurement views including rotational displacement of the plate and a translational displacement (or another rotation about a different pivoting point) of the plate.

2) The pivoting points must be at different stage positions.

3) The lattice generated by the initial pivoting point pair must be dense.

However, the algorithm proposed was computationally expensive because it was non-linear and possible unstable in the presence of large random measurement noise.

An improved method for performing complete self-calibration of metrology stages was disclosed in US 5,798,947 to Ye et al., by mapping each of a two-dimensional array of stage positions (u,v) to a corresponding position in a Cartesian coordinate grid (x,y) to determine the distortion there between. This mapping function is performed by a series of operations which use an orthogonal Fourier series to decouple the determination of a distortion function. A disadvantage with the method is that a rigid artefact plate having a two-dimensional N x N array of marks thereon, having a predetermined interval, has to be provided when making the measurements. Another disadvantage is that the rotation has to be ±90° and the translation has to be at least one interval.

Summary of the invention

An object of the invention is to provide a method for self calibration of a metrology stage where a non-rigid plate can be used when calibrating the metrology stage.

A further object with the invention is that a plate may be used where the position of the marks are not known in advance, i.e. arbitrary scattered across the surface of the plate.

A solution to these objects is achieved by using a method as defined in claim 1.

An advantage with the present invention is that the …

Brief description of the drawings

Fig. 1 shows a flow chart over the measurement procedure for collection of position data to perform self-calibration according to the invention.

Fig. 2 shows a flow chart over the self-calibration procedure according to the invention using the measured position data.

Fig. 3

Detailed description of preferred embodiments

The principal that the method according to the invention is based upon makes it possible to use a calibration plate which is provided with a number of marks arbitrary scattered across the surface of the plate. A plate provided with N x N arrays of marks in a grid structure may naturally also be used. The method will provide a possibility to determine the stage distortion function S(x,y) and also the plate distortion function P(x,y) provided at least three different measurement views has been measured including transitional movement and rotational movement as illustrated in connection with examples below.

The errors between measured positions (u_i,v_i) and the Cartesian coordinates (x_i,y_i) for each measurement point i is a result of errors in the plate and/or errors in the stage. Normally both the plate and the stage contribute to the error in measurement.

The self-calibration is generally performed in the following steps:

1. A calibration plate with marks arbitrary scattered across the surface is provided.

2. An apparatus having means to measure the position of the marks is used, but the stage of the apparatus is not perfect and a correction needs to be done.

3. The calibration plate is arbitrary placed on the stage to establish different measurement views.

The knowledge of the appearance of the stage is rather good and the knowledge of the appearance of the calibration plate is rather good, but "rather good" is not good enough for determining the distortion function for the stage and/or the plate. On the other hand, there is a possibility to perform measurements with high resolution and reproducibility.

Figure 1 shows a flow chart for measuring the position of the marks on the plate in different measurement views for calibration purposes. The flow starts in step 100 and proceeds to step 101, where the flow is fed back to point 102 as long as the system wait for a decision to start gathering position data for a subsequent calibration procedure of the stage. The flow proceeds to step 103 when the gathering begins and a calibration plate provided with marks arbitrary scattered across the surface. The number of marks is typically 400-500 for a plate having the size 800 x 800 mm. An integer M is set to 1 (M=1) in step 104, where M stands for the number of different measurement views. In the following step 105, the plate is placed in a first position (M=1) on the stage. The positions for each mark in at least the x and y direction is measured in step 106 and the result from the measurement is stored in a memory or database, step 107. In step 108 the value of M is checked, and if M<3 the flow is fed back to point 109 via step 110, where the value of M is increased by

one (M=M+1), and step 111, where a new measurement view is determined including translation movement and rotational movement. Steps 105 to 108 are repeated until $M \geq 3$ and the flow continues to step 112, where it is possible to measure additional measurements views. If another measurement view is to be measured, the flow is fed back to point 109 via step 110 and step 111, as described before, and steps 105 to 108 are repeated again. The flow ends in step 113 if no more measurements are to be performed and if no calibration procedure is to be performed (step 114). If, on the other hand, the calibration procedure is to be performed, the flow proceeds to step 200 in figure 2.

Table 1 shows what facts are known and what facts are not known when measurements have been performed.

Known	Not known
- The result of the measurements	- The exact appearance of the plate - The stage correction function (distortion) - The placement coordinates for the plate for every measurement (x,y,α)

Table 1

If the facts were the other way around, and the only unknown fact was the result of the measurements, then it would have been rather easy to calculate them provided the exact position for all marks on the plate, the corrections that have to be applied to obtain a perfect coordinate system and the

placement coordinates for the plate for different measurement views were known.

A numerical approach to the problem will result in an equation system that has to be solved having unknown:

- 2 * N (the number of marks) on the plate, N is typically 400-500.
- Approximately 2 * N on the stage
- 3 * M (the number of measurement views)

The known are 2*N*M, which means that there are more known than unknown provided at least three (3) measurements are performed. The equation system is uncomplicated, almost linear, rather thin (diagonal) and can be solved through a simple iterative method, which is described in connection with figure 2.

The flow starts in step 200, and in step 201, a check is made to determine if enough measurements of different measurement views was carried out in the steps described in figure 1. If the method decides that not enough measurement views have been measured to solve the equation system, the flow is fed back to point 109, in figure 1, via step 110 and 111. Steps 105 to 108 and 112 are repeated and the flow is returned to figure 2 from step 114.

When enough measurement views have been measured the flow continuous to step 202, the stage correction function $S_0(x,y,\alpha)$ is preferably set to zero for all positions, i.e. we assume the stage is perfect and no distortion function is present, since the actual distortion of the stage is very low. It is however possible to assume any other distortion function to the stage initially, the function of the actual distortion

will converge but it may take a little longer time due to more calculations.

A plate approximation is calculated in the following step 203, from each measurement of position data $N(x,y)$ for each measurement view M. That is, in this early stage of the calibration procedure, the measurement made in each measurement view is considered to be a description of the plate if the correction function is set to zero in step 202, otherwise each measurement have to be compensated by the stage correction function.

Thereafter, an average value for each measured position on the plate for all M descriptions is calculated, and is considered to be a first model of the plate – $P_1(x,y)$. This model of the plate is then used to estimate the position of the plate for each measurement, i.e. in each measurement view.

In step 204, simulated measurements M_{SIM} are then calculated using the model of the plate $P_1(x,y)$ and the description of the stage $S_0(x,y,\alpha)$ which is zero for all positions. The calculations are performed by using pure geometrics, and the deviations between the simulated measurements and the "real" measurements for each measurement view will generate a standard deviation value (3σ) describing the in step 205, which indicate how well the stage correction function compensates for the actual appearance of the stage.

In step 206, the standard deviation value - 3σ is compared with a predetermined value, and if 3σ is greater than the predetermined value (i.e. 3σ is not ok!) the flow will proceed to step 208, where a new description of the stage $S_1(x,y,\alpha)$ is calculated using deviations between the previously calculated simulated measurements M_{SIM} (using the previous stage

description $S_0(x,y,\alpha)$ and the model of the plate $P_1(x,y)$) and the actual measurements for each measurement view.

M new descriptions of the plate is thereafter calculated in step 209 using the new stage description $S_1(x,y,\alpha)$. The average value for the measured positions in all measurement views is thereafter calculated for each position and a new model of the plate P_2 is calculated. The flow is thereafter fed back to point 210 and steps 204-206 are repeated until the standard deviation 3σ is less than the predetermined value. The flow ends in step 207 and the latest calculated description of the stage determines the correction function that will be applied to the stage.

Figure 3 illustrates an example of a standard deviation 3σ converging when performing the method previously described. The first assumption with the stage distortion being set to zero, result in a standard deviation of 33 nm, the stage correction function is calculated and a new plate correction function is calculate using the new stage correction function. A new deviation is calculated and the stage function is starting to converge, 3σ=23 nm. The loop is repeated until 3σ is less than a predetermined value, e.g. 5 nm, which means that the method is completed after 7 repetitions. The method may also be completed when a certain number of repetitions have been performed, e.g. 10 repetitions, which will give a 3σ of approx 2 nm in this example.

This application is related to the concurrently filed U.S. Application that names the same inventors, titled "A method for writing a pattern on a surface intended for use in exposure equipment and for measuring the physical properties of the surface" the entire contents of which are incorporated herein by reference.

When performing the self-calibration it could be advantageous to also compensate for the unevenness that exists in both the stage and the artefact plate, as disclosed in the above mentioned concurrently filed US Application.

Step 106 in the flow chart in figure 1 then has to be modified to include to also measure the height, i.e. the z coordinate for each mark. An additional step is inserted between step 106 and step 107, where the unevenness is compensated by calculating a local offset for the measured x and y position for each mark using a reference surface. The result is a 2-dimensional z-correction function that is applied to the measured x and y coordinates. Step 107 is thus modified to include the storing of corrected position data for each mark instead of just saving the measurement.

The working principal to obtain the z-correction function is to measure and/or calculate the gradient at the position of each mark.

The calculating means for performing the method is preferably implemented in a computer program that controls the measuring apparatus.